Northwest and
Alaska
Fisheries Center

National Marine
Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 83-22

The Numbers and Distribution of Walleye Pollock Eggs and Larvae in the Southeastern Bering Sea

December 1983

THE NUMBERS AND DISTRIBUTION OF WALLEYE POLLOCK EGGS AND LARVAE IN SOUTHEASTERN BERING SEA

by

Suam Kim

and

Arthur W. Kendall, Jr.

School of Fisheries
University of Washington
Seattle, Washington 98195

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest and Alaska Fisheries Center
2725 Montlake Boulevard East
Seattle, Washington 98112

December 1983

INTRODUCTION

Our interest and knowledge in walleye pollock, Theragra chalcogramma, the most abundant commercial fish in North Pacific Ocean has increased through last decade. At the same time, interest in petroleum development in the area has increased. Our present research is prepared to exam some possible effects of oil pollution on fish in southeastern Bering Sea. In walleye pollock the planktonic egg and larva is the life history stage that would most likely be severly impacted by oil pollution. Therefore we have examined the amount of spawning and its distribution in time and space in southeastern Bering Sea.

The main spawning ground of walleye pollock is located between Unimak Pass and the Probilof Islands. Spawning occurs during a fairly long season, primarily in spring.

METHOD AND DATA

The spatial and temporal distribution of spawning is inferred from the distribution of the planktonic eggs. For the spatial scales used in our analysis, and considering the generally low velocity of currents in the southeastern Bering Sea, differences in the spatial distribution of eggs and of spawning cannot be detected. The eggs require between 2-3 weeks to hatch at the temperatures at which they occur. Thus, the temporal distribution of spawning would be displaced 2-3 weeks earlier than the occurrence of eggs. Considering egg mortality the actual displacement would probably be less.

We reviewed information about walleye pollock egg and larval distribution from various ichthyoplankton surveys, and collected available data from them.

Our area of concern, the southeastern Bering Sea, has been examined by research teams from several different countries (U.S., U.S.S.R., Japan). However, because each team had different sampling strategies as well as different sampling gear, comparing their data is very difficult and dangerous. Therefore, we chose U.S. scientists' ichthyoplankton surveys (Waldron, 1978; Waldron and Vinter, 1978; and Walline, 1981) that used same gear and same sampling methods for surveys during 1977, 1978, and 1979.

From 1977 to 1979, the sea surface temperatures near Pribilof Islands were warmer than the average (Niebauer, 1980) while from 1973 to 1976 they were colder than the average. However, the average sea surface temperatures during March, which is assumed to be important time for pollock spawning, were nearly the same from 1977 to 1979. Therefore we feel it is reasonable to assume that there was no difference in pollock spawning pattern among the years 1977-79 (the temperature during April 1977 was below normal, although it was above normal in March and May).

In order to investigate the pattern of temporal and spatial spawning and egg and larval distribution, we divided our research area to 37 rectangles of 0.5 degree of latitude by 1 degree of longitude each (Fig. 1). We calculated the areas of the small rectangles based on Lafond (1957). For better temporal resolution, we divided the 1977 cruise into four surveys. We then arranged the U.S. ichthyoplankton surveys in seasonal sequence and assigned them Roman numbers as follows:

Survey I ; March 10-26, 1978; Waldron (1978)

Survey II : April 16-22, 1977; Waldron and Vinter (1978)

Survey III ; April 23-27, 1977; Waldron and Vinter (1978)

Survey IV ; May 3-9, 1977; Waldron and Vinter (1978)

Survey V ; May 10-15, 1977; Waldron and Vinter (1978)

Survey VI ; June 1-23, 1979; Walline (1981)

As metioned above, we divided our research area to 37 subareas. The total number of eggs or larvae in a subarea was calculated by multiplying their average number per square meter by the area of the subarea in square meters. Appendix III includes results of eggs and larval abundance calculations for each subarea.

To arrive at the temporal distribution of spawning, we assumed uniform spawning activity within the total sampling area. Therefore the total amount of eggs present in the entire samping area during each specific survey was calculated by multiplying the area occupied by each station by sum of numbers of eggs present per square meter through all stations.

Generally spawning activity with time approximates a normal distribution. Therefore we could make a normal distribution curve of pollock egg abundance with time from a polynomial equation (Tanaka, 1962) based on the above data sources:

The normal distribution curve is

$$F(X) = \frac{N}{S\sqrt{2\pi}} e^{-\frac{(x-m)^2}{2S^2}}$$

where N = total number of individuals,
S = standard deviation of distribution
m = mean of distribution,
X = abscissa, Julian day,
π = 3.14159

Taking natural logarithms, we get

$$\ln (F(X)) = (\ln \frac{N}{S\sqrt{2\pi}} - \frac{m^2}{2S^2}) + (\frac{m}{S^2})\, X - \frac{1}{2S^2}X^2$$

This is the parabola, also called the second degree polynomial which has form of $Y=A + BX + CX^2$. Because we can get the values of the constants (A, B, and C) by use of a computer, N, m, and S can be calculated;

$$A = \ln (\frac{N}{S\sqrt{2\pi}}) - (\frac{m^2}{2S^2})$$

$$B = \frac{m}{S^2}$$

$$C = - \frac{1}{2S^2}$$

For comparison with our study based on U.S. data, we made another normal distribution curve of pollock egg abundance with time from Moiseev and Bulatov's (1979) data. Because Moiseev and Bulatov (1979) did not include information about egg production during June, we used a digitizer to calculate egg production during June from Kendall (NWAFC, unpublished graph which was based on Bulatov (1979)).

Based on U.S. scientists' ichthyoplankton survey data, total egg production can be estimated as in Houde (1977), assuming there were no significant differences of spawning pattern during 1977-79, i.e., we combined data by month ignoring the year of the survey.

$$N = \Sigma((N_i \cdot D_i/a)$$

where N is the total eggs spawned during one spawning season,

N_i is the number of eggs present in survey i

D_i is the duration of survey i

a is egg hatching time

Fecundity and age composition data of pollock enable us to make an egg production estimation.

There are several data sources for age composition, fish fecundity-length or weight relationship, and von Bertalanffy parameters. After considering all of the data sources, we used data of Smith (1978), Shew (1978), Niggol (1982), and Niggol (1982), respectively because they appeared most reasonable.

In order to calculate the total biomass of eggs spawned, we used egg density data from Kanoh (1954) and egg diameter data from Nishiyama and Haryu (1981).

In general, fecundity of fish is expressed by

$$\text{Fecundity} = A \cdot L^B \qquad (1)$$

where A and B are constants, and L is the length of fish.

$$\text{Fecundity} = E \cdot W^F \qquad (2)$$

where E and F are constants, and W is the weight of fish.

And weight of fish is

$$W = C \cdot L^D \tag{3}$$

where C and D are constants.

Because the length and weight of fish is the function of time, we can express them with time from von Bertalanffy equation;

$$L_t = L\infty(1-e^{-K(t-t_o)}) \tag{4}$$

$$W(t) = W\infty(1-e^{-K(t-t_o)})^D \tag{5}$$

where L_t and Wt = the length and weight at age t

$L\infty$ and $W\infty$ = the asymptotic value of length and weight

K = a relative growth completion rate

t_o = a hypothetical age of zero size

d = a dimensionless exponent reflecting absolute growth rate.

If we combine (1) and (4), and (2), (3) and (5) with each other, we get two fecundity equations with time as follow:

$$\text{Formula I} : \text{Fecundity } (t) = A\ L\infty(1-e^{-K(t-t_o)})^B$$

$$\text{Formula II:}\quad \text{Fecundity }(t) = E\ (W\infty(1-e^{-K(t-t_o)})^D)^F$$

From these we can get the total numbers of egg produced by multiplying fecundity by the total number of females spawning;

$$N = \Sigma(F_t \cdot N_t)$$

where N is the total number of eggs sapwned

F_t is the fecundity of age t fish

N_t is the number of fish at age t.

RESULTS

As mentioned before, we divided our research area to 37 subareas and calculated the number of eggs and larvae present in each area during each survey (Table 1 and Fig. 2). It appears that spawning is active on upper slope area during March, it moves to middle and outer shelf during April, and moves to northwestward later in the spawning season. Roughly speaking, spawning is active at around the 100 m isobath in the southeastern Bering Sea although spawning activity probably depends on several abiotic factors in addition to depth. The larval distribution in Fig. 2 shows seaward movement of larvae after hatching. This pattern of larval distribution was also observed by Serobaba (1974).

After the numbers of egg present at each station during each survey were calculated (Appendix I), the total number of eggs present in our research area during each survey was calculated (Table 2). Also egg numbers present in eastern Bering Sea from Moiseev and Bulatov (1979) and Kendall (NWAFC, pers. comm.) during 1978 spawning season were calculated (Table 3).

When we assumed that the spawning started on the middle of February, the normal distribution based on the above data indicates that 104.4th Julian day (14 April) is the peak of spawning with a standard deviation of 13.8 days (Fig. 3: $F(X) = 27.08e^{-\frac{(X-104.41)^2}{382.16}}$). Also under the same assumption, the result derived from Moiseev and Bulatov (1979) and Kendall (pers. comm.) shows 107.9th Julian day (18 April) as the peak of spawning and 26 days as one standard deviation (Fig. 3: $F(X) = 15.56e^{-\frac{(X-107.94)^2}{1428.82}}$), although smaller egg production was indicated by the Soviets' data than by U.S. scientists'. These results are not significantly different from others which indicate that along the slope and outer shelf the peak spawning occurs in March and April (Lynde, 1983).

Larvae were found beginning in the middle of March in southeastern Bering Sea. Table 1 shows that the maximum larval abundance occurred at around second survey, which was conducted just after peak spawning, and that the number of larvae decreases with time. Walline (1983) calculated the egg hatching dates for pollock from 1979 survey data; hatching dates were distributed from 1 April to 15 July; the hatch was most pronounced during the last 2 weeks in April and the last 2 weeks in May.

Based on Table 2, (ichthyoplankton survey data), the total number of pollock eggs produced during the spawning season in southeastern Bering Sea was estimated. If development time from spawning to hatching is assumed to be

17.3 days which corresponds to duration of the pollock egg stage in 4°C seawater (Richard Bates, NWAFC pers. comm.), the total number becomes 3.6918 E+13 eggs (282.7 eggs/m^2) (see Appendix II).

Also we calculated pollock egg production by knowing the fecundity-age composition relationship of the adult population, although more research is needed to estimate the parameters more precisely for pollock in the eastern Bering Sea. For calculations of number of eggs produced the following constants were used: von Bertalanffy constants of K=0.209, to = -0.315 year, L_∞ = 65.01 cm (Niggol, 1981); Shew's fecundity-length relationship data (1978); and Smith's age compositon data (1981). If we multiply fecundity by number of females at each age, the caculation resulted in 6.17 · E+13 eggs in 159,100 km^2 which equals a density of 387.95 eggs/m^2. For transforming this number to total weight of eggs produced, we multiplied the total number of eggs by the average density of egg (Kanoh, 1954), 1.021, and mean egg volume of 0.0027 cm^3 which came from Nishiyama and Haryu (1981). The total weight of eggs produced in the spawning area of 159,100 km^2 is about 170,000 mt in one spawning season.

DISCUSSION

The egg density derived from fecundity data (387.95 eggs/m^2) is higher than that of the ichthyoplankton surveys (282.7 eggs/m^2) and that of Serobaba (1968) (293.44 eggs/m^2). This indicates that spawning probably occurs outside the areas sampled during these ichthyoplankton surveys. Also catchability of eggs may be less than 100% with the methods used in these surveys.

In performing this study, the biggest problem is in data variation. Because small numbers of ichthyoplankton surveys have been conducted in Bering Sea and data collecting methods have varied, we needed to use many assumptions, which should be reconsidered when more data becomes available. Also the basic biology of pollock is not well understood. We do not know the exact spawning time of pollock in southeastern Bering Sea nor do we understand the variation in size of pollock eggs, which influences our estimation of pollock egg biomass. In order to understand pollock in Bering Sea more exactly, we need to increase research activities to study their biology in relation to oceanographic conditions.

CONCLUSIONS

Spawning occurs over a large area of the southeastern Bering Sea, mainly between the Pribilof Islands and Unimak Pass, between the 100-200 m isobaths. Present data are insufficient to resolve the pattern of spawning and larval distribution adequately. The total spawning area was probably not sampled during the surveys considered in this report.

Spawning peaks on about Julian day 104-108 (14-18 April) with a standard deviation of between 14 and 26 days, based on two sets of ichthyoplankton surveys. Some spawning occurs from about 15 February through June.

Based on fecundity and size of the adult population, 6.17 $\cdot$ E+13 eggs are produced during the spawning season. Based on ichthyoplankton surveys 3.69 $\cdot$ E+13 eggs are produced during the spawning season. The difference between these two estimates may partially be a result of the plankton surveys not covering the entire spawning area. The density of egg spawned based on adult population parameters was 388 eggs/m^2 while that based on plankton surveys was 283 eggs/m^2. This difference may be due in part to problems in plankton sampling and egg mortality.

REFERENCES

Bulatov, O. A. 1979. Distribution of eggs and larvae of walleye pollock and other fish species in the eastern part of the Bering Sea, 1978-1979. Pacific Research Institute Fisheries and Oceanography (TINRO).

Houde, E. D. 1977. Abundance and potential yield of the round herring, Etrumeus teres, and aspects of its early life history in the eastern Gulf of Mexico. Fish. Bull. 75(1):61-89.

Kanoh, Y. 1954. On the buoyancy of the egg of Alaska pollock, Theragra chalcogramma. Japan J. Icchthyol. 3:238-246.

Lafond, E. C. 1957. Processing oceanographic data. H. O. Pub. No. 614, U.S. Hydrographic Office, Washington, D.C.

Lynde, C. M. 1983. Juvenile and adult walleye pollock of the Eastern Bering Sea. Proc. of 1983 Eastern Bering Sea pollock ecosystem workshop. NWAFC.

Moiseev, E. I., and O. A. Bulatov. 1979. The state of pollock stocks in Eastern Bering Sea. Pacific Research Inst. of Fisheries and Oceanography (TINRO).

Niebauer, H. J. 1980. Sea ice and temperature variability in the eastern Bering Sea and the relation to atmospheric fluctuations. J. Geophys. Res. 85:7507-7515.

Niggol, K. 1982. Data on fish species from Bering Sea and Gulf of Alaska. NOAA Tech. Memo. NMFS F/NWC-29.

Nishiyama, T. and T. Haryu. 1981. Distribution of walleye pollock eggs in the upper most layer of the Southeastern Bering Sea. In: Hood, D. W. and J. A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources Vol. 2 (Chap. 59), pp. 993-1012, U.S. Dept. of Comm. NOAA.

Serobaba, I. I. 1968. Spawning of Alaskan pollock, Theragra chalcogramma (Pallas), in the Northeastern Bering Sea. Vopr. Ichthyol. 8(6), 789-798.

Serobaba, I. I. 1974. Spawning ecology of the walleye pollock, Theragra chalcogramma, in the Bering Sea. J. Ichthyol. 14:544-552.

Shew, P. M. 1978. Pollock fecundity study; Preliminary report. NMFS, NWAFC, unpub. MS.

Smith, G. B. 1981. The biology of walleye pollock. In: Hood, D. W. and J. A. Calder (Eds.), The eastern Bering Sea Shelf: Oceanography and Resources. VI. (Ch. 33) pp 527-551. U.S. Dept. of Comm., NOAA.

Tanaka, S. 1962. A method of analyzing a polymodal frequency distribution and its application to the length distribution of porgy, Taius tumifrons. J. Fish. Res. Bd. Canada, 19(6).

Waldron, K. D. 1978. Ichthyoplankton of the eastern Bering Sea. NMFS, NWAFC, Proc. Rep.

Waldron, K. D., and B. M. Vinter. 1978. Ichthyoplankton of the eastern Bering Sea. NMFS, NWAFC, Proc. Rep.

Walline, P. D. 1981. Distribution of ichthyoplankton in the Eastern Bering Sea during June and July, 1979. NMFS, NWAFC, Proc. Rep. 81-03.

Walline, P. D. 1983. Growth of larval and juvenile walleye pollock related to year-class strength. Ph.D. Thesis, Univ. of Washington.

Table 1.--The total numbers of eggs (E+11) and larvae (E+11) present in each sub area during each survey. Larval data are in parentheses.

Subarea	Survey I	II	III	IV	V	VI
A(1,1)		0.0000 (0.000)			1.3560 (0.428)	
A(1,2)		0.0381 (0.114)			1.8716 (0.496)	0.0000 (0.000)
A(1,3)						0.0000 (0.024)
A(1,4)						0.0221 (0.092)
A(1,5)						0.1158 (0.719)
A(2,1)						0.0000 (0.000)
A(2,2)			1.0005 (1.221)		0.0867 (0.737)	0.0000 (0.024)
A(2,3)			1.2447 (0.181)		0.8949 (0.291)	0.0000 (0.000)
A(2,4)			0.5220 (0.019)		0.6674 (0.000)	0.0079 (0.075)
A(2,5)			12.9470 (0.000)	3.7147 (0.000)		
A(3,1)					0.0485 (0.388)	
A(3,2)	0.0193	0.0397 (0.218)			0.0413 (0.496)	0.0000 (0.000)

Subarea	Survey I	II	III	IV	V	VI
A(3,3)	0.0182	0.1532	0.1871		0.4421	0.0000
		(0.153)	(0.122)	(1.118)		(0.103)
A(3,4)	0.0000	0.1547	0.1793		0.2623	0.0000
		(0.000)	(0.021)		(0.031)	(0.123)
A(3,5)	0.0000	0.6378	0.3298	0.7144		
		(0.000)	(0.000)	(0.675)		
A(3,6)		25.8220		0.7017		
		(0.000)		(0.000)		
A(4,1)	0.1158					
A(4,2)	2.2444	0.0867			0.0213	0.0000
		(12.113)			(0.255)	(0.000)
A(4,3)	0.0550	0.1239	0.3672	0.1437	0.2008	0.0000
		(0.137)	(0.516)	(1.265)	(3.414)	(0.015)
A(4,4)	0.0000	0.0186	0.0102	0.1648		
		(0.008)	(0.051)	(0.991)		
A(4,5)	0.0309	1.3577	3.9712	2.2624		
		(0.071)	(0.135)	(0.822)		
A(4,6)	0.0000	2.5091	11.9090	7.6239		
		(0.000)	(0.000)	(0.590)		
A(4,7)				0.4143		
				(0.000)		
A(5,1)	0.0000					
						(0.025)

Subarea	Survey I	II	III	IV	V	VI
A(5,2)	0.2358	0.5192		0.0677		0.0000
		(16.817)		(0.293)		(0.000)
A(5,3)	34.3490	0.0160	0.0483	0.0990		0.0000
		(1.495)	(6.884)	(2.299)		(0.012)
A(5,4)		0.1257	0.5852	0.4044		0.0000
		(3.839)	(3.162)	(0.929)		
A(5,5)	0.0184	0.6430	0.6932	0.6790		
		(0.047)	(0.158)	(0.980)		
A(5,6)		0.0559	0.0000	0.1966		
		(0.000)	(0.000)			
A(6,1)						0.0000
A(6,2)		0.1382	0.1100	0.2351	0.0882	
		(0.737)	(2.134)	(2.962)	(0.639)	
A(6,3)	1.0763	0.0223	0.0206		0.0758	
		(2.053)	(5.615)		(0.162)	
A(6,4)	0.0000	0.4393	5.3085	0.7404	0.0468	
		(4.675)	(2.628)	(0.912)	(0.937)	
A(6,5)	0.0000	2.2694	13.9810	2.5505		
		(5.266)	(8.063)	(0.548)		
A(7,1)				0.2068		
				(3.392)		
A(7,2)			0.2745	0.1067		
			(5.108)	(1.328)		

Subarea	Survey I	II	III	IV	V	VI
A(7,3)		0.4877 (20.950)			0.0843 (0.139)	
Total (E+11)	38.163	35.620 (68.686)	53.689 (36.018)	21.027 (19.104)	6.188 (8.413)	0.146 (1.212)
Mean (E+11)	2.245	1.781 (3.122)	2.557 (1.801)	1.168 (1.061)	0.413 (0.601)	0.009 (0.076)
No. animals/ survey (E+11)	87.55	69.46 (109.27)	99.71 (63.03)	45.56 (37.14)	16.09 (21.04)	0.34 (2.65)

Table 2. Summary table of egg for U.S. scientists' data.

Survey duration	Mid-day of survey (Julian day (X))	No. of station sampled	Total eggs during survey (E+11 eggs)	Number of survey days	No. of eggs sampled/day (E+11)
Feb. 14	45			1	0.001
Mar. 10-16	71	21	70.100	7	10.010
Apr. 16-22	108	35	119.832	7	17.119
Apr. 23-27	114	31	90.430	5	18.086
May 3-9	125	28	40.505	7	5.786
May 10-15	131.5	17	14.564	6	2.427
June 1-23	162	39	0.170	22	0.008

Table 3. The number of eggs present in spawning areas from Soviet survey.

Survey duration	Mid-day of survey (Julian day (X))	Total eggs during survey (E+8)	No. of eggs sampled per day (E+8)
April 10 - May 3	110.5	294.7	12.28
May 10-20	134.0	151.0	13.73
June 1-30	166.0	40.2	1.34

FIGURES

Figure 1. Research area in southeastern Bering Sea. The size of each subarea is 0.5° latitude by 1° longitude. 100 m isobath is included.

Figure 2. Spatial distribution of pollock eggs and larvae. The three subareas with the greatest densities during each survey are indicated. 100 m isobath is included. (A) Eggs (B) Larvae.

Figure 3. The relative abundance of pollock egg with time. (A) Based on U.S. scientists' data. (B) Based on Moiseev and Bulatov (1978) and Kendall (pers. comm.).

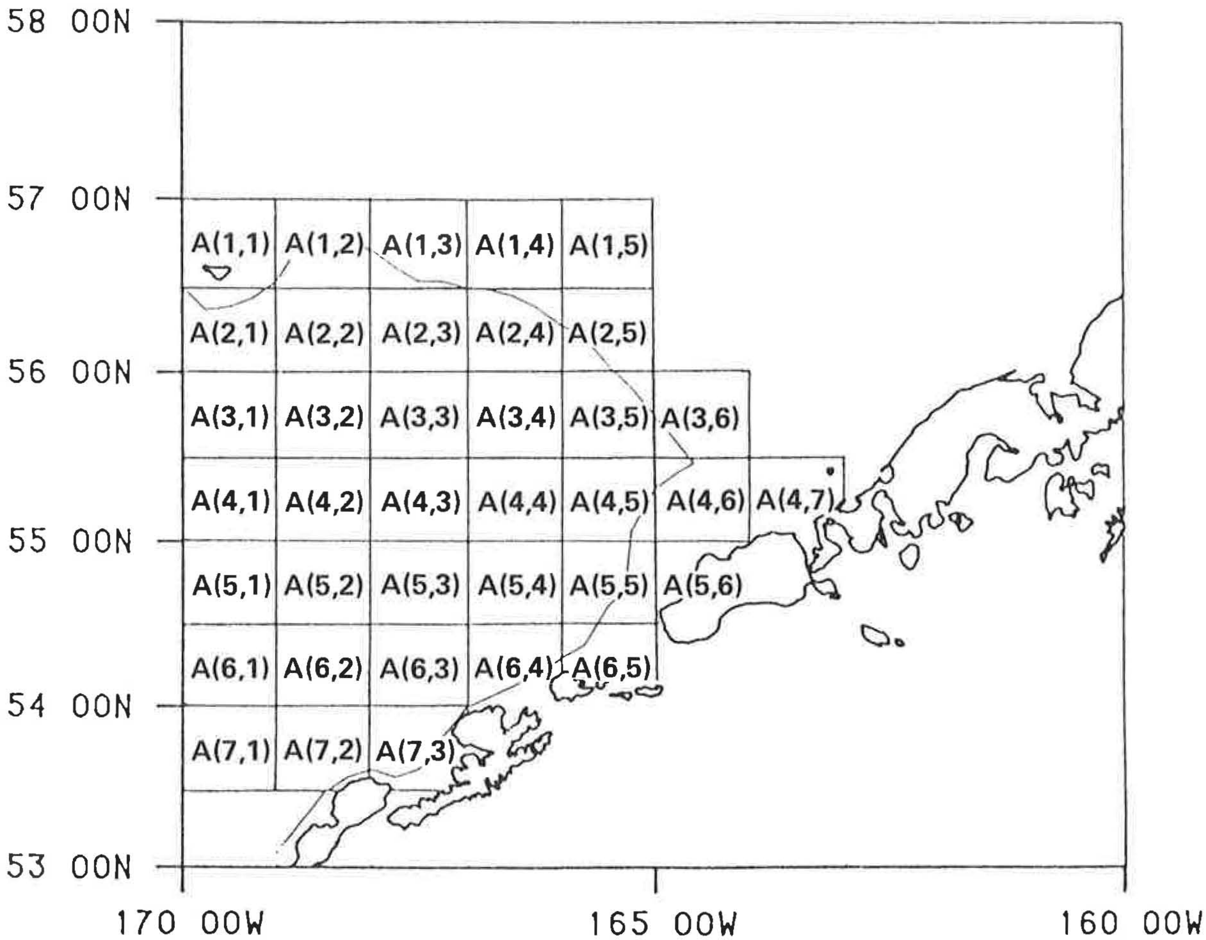

Figure 1. Research area in southeastern Bering Sea. The size of each subarea is 0.5° latitude by 1° longitude. 100 m isobath is included.

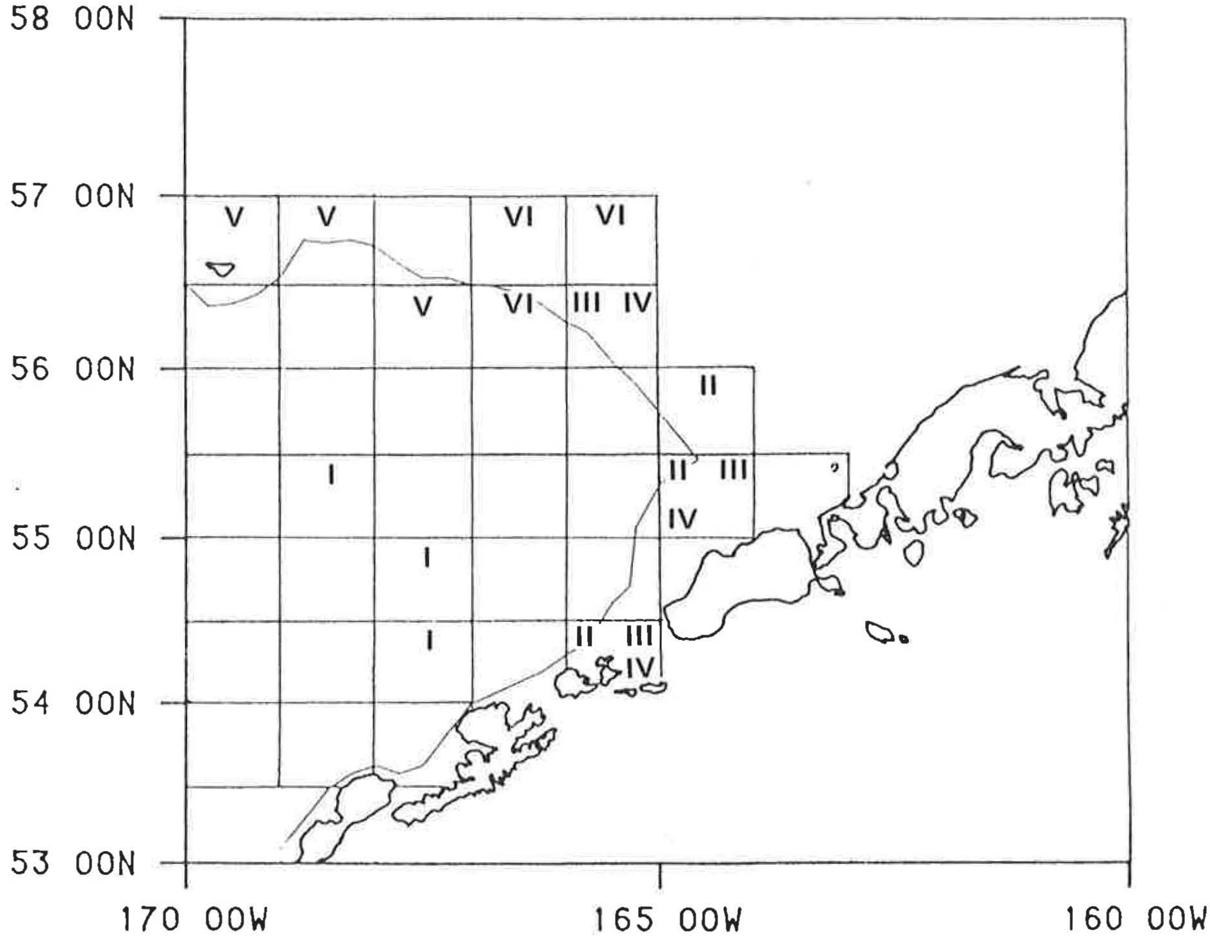

Figure 2. Spatial distribution of pollock eggs and larvae. The three subareas with the greatest densities during each survey are indicated. 100 m isobath is included. (A) Eggs.

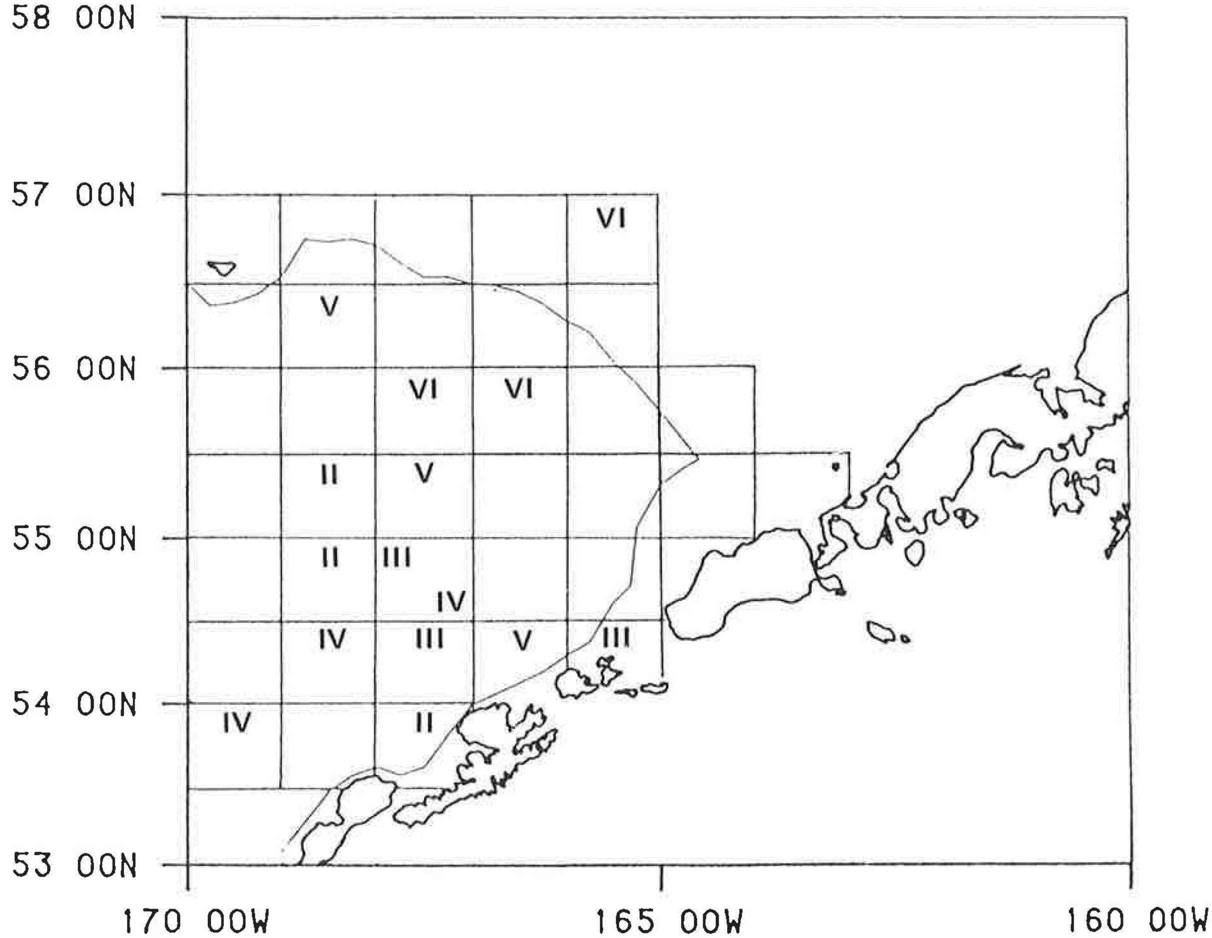

Figure 2. Spatial distribution of pollock eggs and larvae. The three subareas with the greatest densities during each survey are indicated. 100 m isobath is included. (B) Larvae.

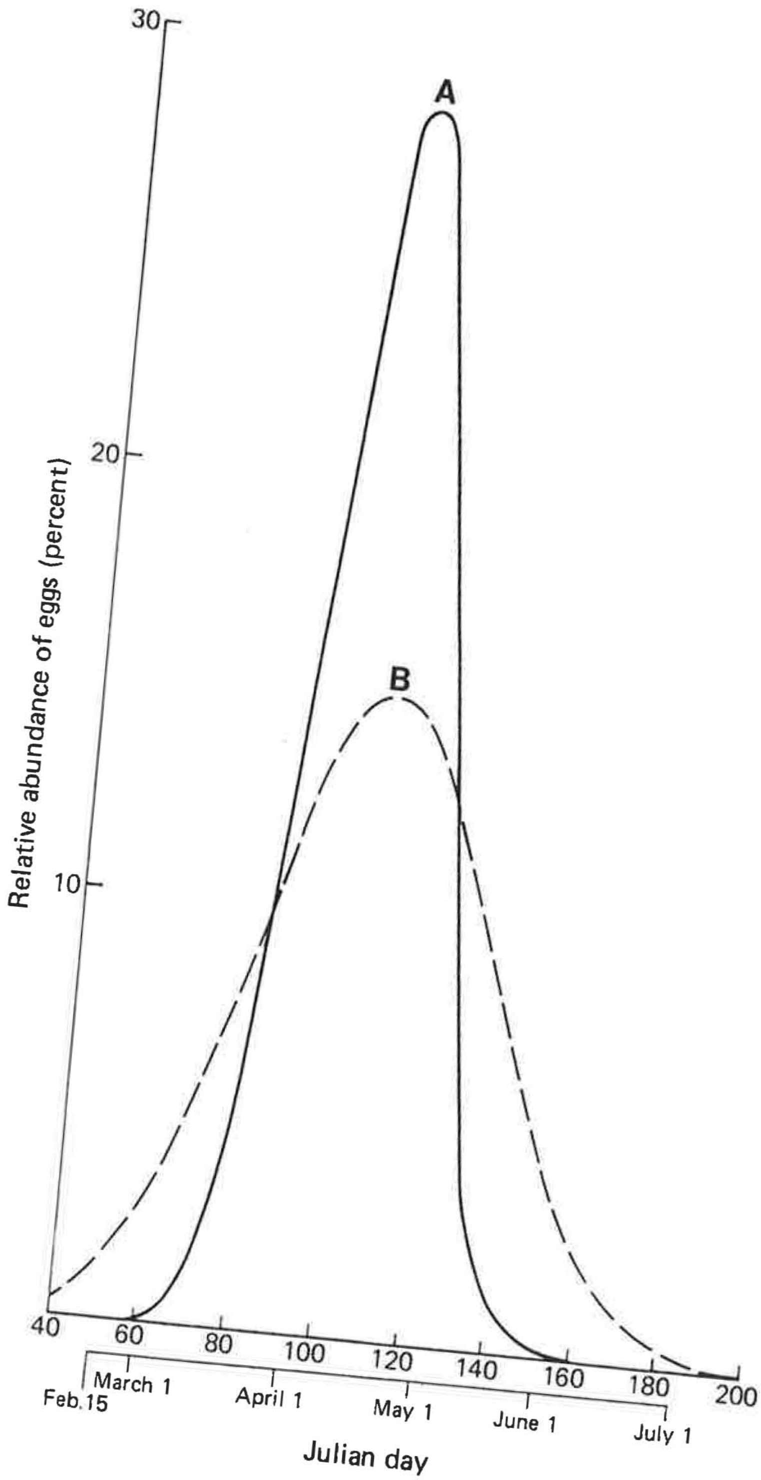

Figure 3. The relative abundance of pollock egg with time. (A) Based on U.S. scientists' data. (B) Based on Moiseev and Bulatov (1978) and Kendall (pers. comm.).

Appendix I: The number of eggs present at each station during each survey.

1) The total number of eggs present at each station during March 10-16, 1978. (Survey I)

Station	No. of eggs sampled during survey	SHF	No. of eggs/m^2
16	203	4.252	86.3156
17	5	5.379	2.6895
18	11	5.980	6.5780
19	1858	5.158	958.3564
20	100	6.340	63.4000
21	6	5.450	3.2700
22	1	5.494	0.5494
23	4	4.876	1.9504
24	1	5.181	0.5181
28	2	5.791	1.1582
29	3	5.817	1.7451
32	1	5.147	0.5147
		Total	1127.0454

SHF (Standard Haul Factor) converts actual catch to numbers beneath 10 m^2 of sea surface.

Total number of egg present in area of concern = $(130613.6 \cdot 1000000/21) \cdot 1127.045$
$= 7.0099 \cdot E+12$

2) The number of eggs present at each station during April 16-May 15, 1977.*

Station	Survey II			Survey III			Survey IV			Survey V		
		No. of eggs			No. of eggs			No. of eggs			No. of eggs	
	SHF	total	$/m^2$	SHF	total	$/m^2$	SHF	total	$/m^2$	SHF	total	$/m^2$
1	6.55	30	19.635	6.69	427	285.834	6.62	58	38.367			
2	5.73	8	4.584	6.19	11	6.810	6.12	4	2.448	6.46	2	1.219
3	4.99	1	0.499	6.53	1	0.653	5.42	6	3.253			
4	3.92	1	0.392	6.80	3	2.041	5.68	4	2.272			
5	3.04	11	3.347	6.77	6	4.059				5.67	10	5.672
6	4.06	9	3.653	5.96	28	16.685	4.06	10	4.059			
7	5.53	2	1.106	6.54	24	15.698	4.86	19	9.234			
8	5.91	10	5.910	6.28	27	16.956	5.80	23	13.333	Bongo tow aborted		
9	4.73	131	62.553	5.68	678	385.375	5.81	121	70.301			
10	4.77	12	5.725	5.49	9	4.945	4.78	55	26.301			
11	5.20	58	30.154	5.84	58	33.855	5.04	23	11.587			
12	4.34	-	-	6.38	-	-	4.81	15	7.221			
13	5.25	2	1.050	5.78	1	0.578	4.18	5	2.091			
14	5.50	3	1.650	5.96	4	2.385				5.75	16	9.197
15	5.04	14	7.062	5.50	15	8.252				5.50	29	15.936
16	6.00	7	4.202	5.59	14	7.829				5.99	22	13.174
17	5.10	9	4.594	5.91	4	2.363	5.79	3	1.736			
18	5.00	6	2.998	5.87	-	-	5.15	4	2.059			
19	5.38	137	73.706	6.03	372	224.353	5.54	227	125.758			
20	5.20	3	1.561	5.73	-	-	5.49	10	5.485			
21	4.34	2	0.868	4.54	121	54.922	4.52	-	-			
22	5.73	246	140.884	5.50	1123	617.875	4.90	879	430.710			
23	5.82	36	20.941	5.58	25	13.958	5.18	68	35.251			
24	6.38	24	15.314	5.99	8	4.790	5.36	10	5.360			
25	5.98	1741	1041.466				5.08	16	8.120			
26	6.96	682	474.536				5.12	62	31.769			
27	Bongo tow aborted						4.07	54	21.967			
39	5.60	2	1.120							4.70	117	54.943
40	4.86	-	-							5.24	76	39.809
49	6.35	6	3.808				6.48	10	6.479	6.08	4	2.430
50	6.99	19	13.283							7.65	3	2.296
51	6.15	1	0.615							6.85	3	2.055
52	6.30	23	14.485				6.29	3	1.888			
53	6.12	4	2.448							6.01	1	0.601
54	5.64	2	1.128							5.87	2	1.174
55	Bongo tow aborted									6.89	2	1.379
58				5.87	50	29.370				6.37	4	2.546
59				5.89	62	36.537				6.11	43	26.269
60				5.68	27	15.323				6.32	31	19.592
61				5.24	726	380.061	5.65	193	109.045			
62							4.19	142	59.427			
64				6.48	1	0.648				7.07	3	2.122
65				6.06	5	3.032	5.81	5	2.906			
66				6.23	12	7.476	5.63	10	5.633			
	Total =		1965.277			2182.660			984.634			200.486

Total number of eggs present in area of concern: subarea 1; Station No. 1-24
subarea 2; Station No. 25-66

Survey II

	subarea 1:	(4.404 E+10/24)·(19.6350+4.5840+,,,+15.3144)	= 7.5673·E+11
+)	subarea 2:	(5.166 E+10/10)·(1041.4662+474.5356+,,,+1.1282)	= 80.222·E+11
			87.789·E+11

Survey III

	subarea 1:	(4.404 E+10/24)·(285.8338+6.8101+,,,+4.7896)	= 31.382·E+11
+)	subarea 2:	(5.166 E+10/8)·(29.370+36.537+,,,+7.476)	= 34.866·E+11
			66.248·E+11

Survey IV

	subarea 1:	(4.404 E+10/20)·(38.367+2.448+,,,+5.360)	= 17.546·E+11
+)	subarea 2:	(5.166 E+10/8)·(8.120+31.769+,,,+5.633)	= 12.128·E+11
			29.674·E+11

Survey V

	subarea 1:	(4.404 E+10/5)·(1.2912+5.672+,,,+13.174)	= 3.9873·E+11
+)	subarea 2:	(5.166 E+10/12)·(54.943+39.809+,,,+2.122)	= 6.6821·E+11
			10.6694·E+11

*They mentioned that the total area of subarea 1 and 2 is 95700 km^2. Because we assumed equal production rate outside this area, we can corrected that number to 130613.6 km^2 by multiplying 1.365 to total egg number present in subarea 1 and 2;

	Survey			
	II	III	IV	V
Amount of egg present (E+11)	119.832	90.430	40.505	14.564

3) Total number of eggs present at each station during June 1-23, 1979 (Survey VI).

Station	No. of eggs/m^2
V01-8	0.7
S 46A	1.3
S 12A	3.4
Total	= 5.4

Total number of egg present in area of concern = (130613.6·1000000/40)·5.4
= 1.763·E+10

Appendix II: The estimation of total egg number produced.

Survey (i)	N_i (E+11) eggs	D_i days
I	70.10	34.5
II	119.83	22.5
III	90.43	7.5
IV	40.51	9.5
V	14.56	14.0
VI	0.17	31.0

$N = \Sigma((N_i \cdot D_i/a)$
$= (6386.805/17.3)E+11$
$= 369.18 \cdot E+11$ (eggs)

Appendix III: Total number of pollock eggs and larvae in subarea A(i,j) during specific survey.

EGGS

Subarea	No. of times sampled	No. of times egg caught	Survey (station number)	No. of eggs/ m^2	Total No. of eggs present /subarea
A(1,1)	2	1	II (40)	0	0
			V (40)	39.8088	1.3560 E+11
A(1,2)	5	3	II (39)	1.1196	3.8140 E+9
			V (39)	54.9432	1.8716 E+11
			VI (S47A, S48A)	0	0
A(1,3)	1	1	VI (S45A)	0	0
A(1,4)	2	1	VI (S40A, S46A)	1.3000	2.2142 E+9
A(1,5)	1	1	VI (S12A)	3.4000	1.1582 E+10
A(2,1)	2	2	VI (S50A, S53A)	0	0
A(2,2)	4	2	III (58)	29.3700	1.0005 E+11
			V (58)	2.5460	8.6732 E+9
			VI (S41A, S44A)	0	0
A(2,3)	4	2	III (59)	36.5366	1.2447 E+11
			V (59)	26.2687	8.9487 E+10
			VI (S38A, S39A)	0	0
A(2,4)	5	3	III (60)	15.3225	5.2198 E+10
			V (60)	19.5920	6.6742 E+10
			VII (V01-8, S33A, S34A)	0.2333	0.7949 E+9
A(2,5)	2	2	III (61)	380.0610	1.2947 E+12
			IV (61)	109.0450	3.7147 E+11
A(3,1)	2	1	II (55)	Bongo tow aborted	
			V (55)	1.3788	4.8509 E+9
A(3,2)	5	3	I (22)	0.5494	1.9329 E+9
			II (54)	1.1282	3.9692 E+9
			V (54)	1.1740	4.1304 E+9
			VI (S42A, S43A)	0	0

Subarea	No. of times sampled	No. of times egg caught	Survey (station number)	No. of eggs/ m^2	Total No. of eggs present /subarea
A(3,3)	11	7	I (24)	0.5181	1.8228 E+9
			II (14, 15)	4.3557	1.5324 E+10
			III (14, 15)	5.3184	1.8711 E+10
			IV (14, 15)	12.5662	4.4210 E+10
			VI (S08A, S08B S29A, S35A)	0	0
A(3,4)	11	6	I (25)	0	0
			II (16,17)	4.3979	1.5473 E+10
			III (16, 17)	5.0958	1.7928 E+10
			V (16, 17)	7.4546	2.6227 E+10
			VI (S09A, S30A, S31A, S32A)	0	0
A(3,5)	7	6	I (26)	0	0
			II (23, 24)	18.1278	6.3777 E+10
			III (23, 24)	9.3736	3.2978 E+10
			IV (23, 24)	20.3056	7.1439 E+10
A(3,6)	4	4	II (25, 26)	758.0009	2.5822 E+12
			IV (25, 26)	19.9444	7.0168 E+10
A(4,1)	1	1	I (21)	3.2700	1.1576 E+10
A(4,2)	4	3	I (20)	63.4000	2.2444 E+11
			II (53)	2.4484	8.6676 E+9
			V (53)	0.6014	2.1290 E+99
			VI (S13A)	0	0
A(4,3)	13	8	I (23, 28)	1.5543	5.5024 E+9
			II (5, 6)	3.5002	1.2391 E+10
			III (5, 6)	10.3721	3.6719 E+10
			IV (6)	4.0590	1.4369 E+10
			V (5)	5.6720	2.0080 E+10
			VI (S06A, S07A, S28A, S36A, S37A)	0	0
A(4,4)	7	4	I (27)	0	0
			II (12, 13)	0.5251	1.8589 E+9
			III (12, 13)	0.2890	1.0231 E+9
			IV (12, 13)	4.6560	1.6483 E+10
A(4,5)	8	6	I (29, 30)	0.8726	3.0890 E+9
			II (18, 19)	38.3521	1.3577 E+11

Subarea	No. of times sampled	No. of times egg caught	Survey (station number)	No. of eggs/ m^2	Total No. of eggs present /subarea
			III (18, 19)	112.1766	3.9712 E+11
			IV (18, 19)	63.9084	2.2624 E+11
A(4,6)	7	5	I (31)	0	0
			II (21, 22)	70.8759	2.5091 E+11
			III (21, 22)	336.3983	1.1909 E+12
			IV (21, 22)	215.3550	7.6239 E+11
A(4,7)	3	2	II (27)	Bongo tow aborted	
			IV (27)	21.9672	7.7767 E+10
A(5,1)	1	0	VI (S14A)	0	0
A(5,2)	6	3	I (18)	6.5780	2.3577 E+10
			II (52)	14.4854	5.1918 E+10
			IV (52)	1.8882	6.7676 E+9
			VI (S04A, S05A, S27A)	0	0
A(5,3)	10	7	I (19)	958.3564	3.4349 E+12
			II (3, 4)	0.4456	1.5971 E+9
			III (3, 4)	1.3471	4.8282 E+9
			IV (3, 4)	2.7623	9.9005 E+9
			VI (S01A, S02A S03A)	0	0
A(5,4)	8	6	II (7, 8)	3.5078	1.2572 E+10
			III (7, 8)	16.3272	5.8519 E+10
			IV (7, 8)	11.2836	4.0442 E+10
			V (8)	Bongo tow aborted	
			VI (S14A)	0	0
A(5,5)	7	7	I (32)	0.5147	1.8448 E+9
			II (10, 11)	17.9397	6.4298 E+10
			III (10, 11)	19.3996	6.9317 E+10
			IV(10, 11)	18.9442	6.7899 E+10
A(5,6)	3	2	II (20)	1.5609	5.5945 E+9
			III (20)	0	0
			IV (20)	55.4850	1.9659 E+10
A(6,1)	1	0	VI (S26A)	0	0

Subarea	No. of times sampled	No. of times egg caught	Survey (station number)	No. of eggs/ m^2	Total No. of eggs present /subarea
A(6,2)	4	4	II (49)	3.8082	1.3816 E+10
			III (65)	3.0320	1.1000 E+10
			IV (49)	6.4790	2.3506 E+10
			V (49)	2.4304	8.8174 E+9
A(6,3)	7	6	I (15, 16, 17)	29.6684	1.0763 E+11
			II (51)	0.6151	2.2316 E+9
			III (64)	0.6476	2.2061 E+9
			V (51, 64)	2.0885	7.5770 E+9
A(6,4)	8	7	I (12)	0	0
			II (1, 2)	12.1095	4.3933 E+10
			III (1, 2)	146.3220	5.3085 E+11
			IV (1, 2)	20.4077	7.4038 E+10
			V (2)	1.2912	4.6844 E+9
A(6,5)	4	3	I (13)	0	0
			II (9)	62.5525	2.2694 E+11
			III (9)	385.3752	1.3981 E+12
			IV (9)	70.3010	2.5505 E+11
A(7,1)	1	1	IV (66)	5.6330	2.0681 E+10
A(7,2)	2	2	III (66)	7.4760	2.7447 E+10
			IV (65)	2.9060	1.0669 E+10
A(7,3)	2	2	II (50)	13.2829	4.8767 E+10
			V (50)	2.2962	8.4303 E+9

LARVAE

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number)	No. of larvae/ m^2	Total No. of larvae present (E+10)/subarea
A(1,1)	2	1	II (40)	0	0
			V (40)	12.5712	4.2822
A(1,2)	4	2	II (39)	3.3588	1.1441
			V(39)	14.5576	4.9588
			VI (S47A,S48A)	0	0

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number)	No. of larvae/ m^2	Total No. of larvae present (E+10)/subarea
A(1,3)	1	1	VI (S45A)	0.7	0.2384
A(1,4)	1	1	VI (S40A)	2.7	0.9197
A(1,5)	1	1	VI (S12A)	21.1	7.1874
A(2,1)	2	0	VI (S50A,S53A)	0	0
A(2,2)	4	4	III (58)	35.8314	12.2060
			V (58)	21.6410	7.3722
			VI (S41A,S44A)	0.7	0.2385
A(2,3)	4	2	III (59)	5.3037	1.8068
			V (59)	8.5526	2.9135
			VI (S38A,S39A)	0	0
A(2,4)	5	3	III (60)	0.5675	0.1933
			V (60)	0	0
			VI (V01-8, S33A,S34A)	2.2	0.7495
A(2,5)	2	0	III (61)	0	0
			V (61)	0	0
A(3,1)	1	1	V (55)	11.0304	3.8807
A(3,2)	4	2	II (54)	6.2051	2.1831
			V (54)	14.0880	4.9564
			VI (S42A, S43A)	0	0
A(3,3)	9	7	II (14, 15)	4.3557	1.5324
			III (14, 15)	3.4623	1.2181
			IV (14, 15)	31.7734	11.1780
			VI (S08A, S29A, S35A)	2.93	1.0308
A(3,4)	9	5	II (16, 17)	0	0
			III (16, 17)	0.5907	0.2079
			V (16, 17)	0.8779	0.3089
			VI (S09A, S31A, S32A)	3.5	1.2314
A(3,5)	6	1	II (23, 24)	0	0
			III (23, 24)	0	0
			IV (23, 24)	19.1808	6.7482

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number)	No. of larvae/ m^2	Total No. of larvae present (E+10)/subarea
A(3,6)	4	0	II (25, 26)	0	0
			IV (25, 26)	0	0
A(4,2)	3	2	II (53)	342.1639	121.13
			V (53)	7.2168	2.5548
			VI (S13A)	0	0
A(4,3)	11	7	II (5, 6)	3.8558	1.3650
			III (5, 6)	14.5679	5.1572
			IV (6)	35.7192	12.6450
			V (5)	96.4240	34.1350
			VI (S06A, S07A, S28A, S36A, S37A)	0.42	0.1487
A(4,4)	6	4	II (12,13)	0.2171	0.0769
			III (12, 13)	1.4448	0.5115
			IV (12, 13)	28.0048	9.9141
A(4,5)	6	4	II (18, 19)	1.9988	0.7076
			III (18, 19)	3.8155	1.3507
			IV (18, 19)	23.2091	8.2163
A(4,6)	6	1	II (21, 22)	0	0
			III (21, 22)	0	0
			IV (21, 22)	16.66	5.8979
A(4,7)	1	0	IV (27)	0	0
A(5,1)	1	1	VI (S14A)	0.7	0.2509
A(5,2)	5	2	II (52)	469.2010	168.1700
			IV (52)	8.1822	2.9326
			VI (S04A, S05A, S27A)	0	0
A(5,3)	9	7	II (3, 4)	41.7090	14.9490
			III (3, 4)	192.0720	68.8410
			IV (3, 4)	64.1443	22.9900
			VI (S01A, S02A, S03A)	0.3333	0.1195
A(5,4)	6	5	II (7, 8)	107.1016	38.3870
			III (7, 8)	88.2340	31.6240
			IV (7, 8)	25.9135	9.2878

Subarea	No. of times sampled	No. of times larvae caught	Survey (station number)	No. of larvae/ m^2	Total No. of larvae present (E+10)/subarea
A(5,5)	6	5	II (10, 11)	1.2998	0.4659
			III (10, 11)	4.4124	1.5815
			IV (10, 11)	27.3296	9.7953
A(5,6)	3	1	II (20)	0	0
			III (20)	0	0
			IV (20)	2.7425	0.9830
A(6,2)	4	4	II (49)	20.3104	7.3685
			III (65)	58.8208	21.3400
			IV (49)	81.6354	29.6170
			V (49)	17.6204	6.3926
A(6,3)	4	4	II (51)	56.5984	20.5340
			III (64)	154.7764	56.1520
			V (51, 64)	4.4744	1.6233
A(6,4)	7	7	II (1, 2)	128.8466	46.7450
			III (1,2)	72.4442	26.2820
			IV (1, 2)	25.1509	9.1246
			V (2)	25.8240	9.3688
A(6,5)	3	3	II (9)	145.1600	52.6630
			III (9)	222.2444	80.6290
			IV (9)	15.1060	5.4804
A(7,1)	1	1	IV (66)	93.5078	33.9240
A(7,2)	2	2	III (66)	140.7980	51.0810
			IV (65)	36.6156	13.2840
A(7,3)	2	2	II (50)	577.4566	209.5000
			V (50)	3.8270	1.3884